COMESA 303-3 (2007) (English): Power transformers   Part 3: Insulation levels, dielectric tests and external clearances in air

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COMESA HARMONISED STANDARD

COMESA/FDHS 303-3:2007

Power transformers — Part 3: Insulation levels, dielectric tests and external clearances in air

REFERENCE: FDHS 303-3:2007

Foreword

The Common Market for Eastern and Southern Africa (COMESA) was established in 1994 as a regional economic grouping consisting of 20 member states after signing the co-operation Treaty. In Chapter 15 of the COMESA Treaty, Member States agreed to co-operate on matters of standardisation and Quality assurance with the aim of facilitating the faster movement of goods and services within the region so as to enhance expansion of intra-COMESA trade and industrial expansion.

Co-operation in standardisation is expected to result into having uniformly harmonised standards. Harmonisation of standards within the region is expected to reduce Technical Barriers to Trade that are normally encountered when goods and services are exchanged between COMESA Member States due to differences in technical requirements. Harmonized COMESA Standards are also expected to result into benefits such as greater industrial productivity and competitiveness, increased agricultural production and food security, a more rational exploitation of natural resources among others.

COMESA Standards are developed by the COMESA experts on standards representing the National Standards Bodies and other stakeholders within the region in accordance with international procedures and practices. Standards are approved by circulating Final Draft Harmonized Standards (FDHS) to all member states for a one Month vote. The assumption is that all contentious issues would have been resolved during the previous stages or that an international or regional standard being adopted has been subjected through a development process consistent with accepted international practice.

COMESA Standards are subject to review, to keep pace with technological advances. Users of the COMESA Harmonized Standards are therefore expected to ensure that they always have the latest version of the standards they are implementing.

This COMESA standard is technically identical to IEC 60076-3:2000, *Power transformers — Part 3: Insulation levels, dielectric tests and external clearances in air*

INTERNATIONAL STANDARD

IEC 60076-3

Second edition
2000-03

Power transformers –

Part 3:
Insulation levels, dielectric tests and external clearances in air

*This **English-language** version is derived from the original **bilingual** publication by leaving out all French-language pages. Missing page numbers correspond to the French-language pages.*

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As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

Consolidated editions

The IEC is now publishing consolidated versions of its publications. For example, edition numbers 1.0, 1.1 and 1.2 refer, respectively, to the base publication, the base publication incorporating amendment 1 and the base publication incorporating amendments 1 and 2.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER TRANSFORMERS –

Part 3: Insulation levels, dielectric tests and external clearances in air

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.
3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.
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6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60076-3 has been prepared by IEC technical committee 14: Power transformers.

This second edition cancels and replaces the first edition published in 1980, amendment 1 (1981) and IEC 60076-3-1 (1987).

The text of this standard is based on the following documents:

FDIS	Report on voting
14/347/FDIS	14/355/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

Annexes A, B and C are for information only.

Annex D forms an integral part of this standard.

The committee has decided that the contents of this publication will remain unchanged until 2008. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

The contents of the corrigendum of December 2000 have been included in this copy.

INTRODUCTION

This part of IEC 60076 specifies the insulation requirements and the corresponding insulation tests with reference to specific windings and their terminals. It also recommends clearances in air between live parts of bushings on oil-immersed power transformers and to objects at earth potential (clause 16). Guidance can be obtained from IEC 60071.

The insulation levels and dielectric tests which are specified in clauses 4, 5, 6 and 7 in this standard apply to the internal insulation only. Whilst it is reasonable that the rated withstand voltage values which are specified for the internal insulation of the transformer should also be taken as a reference for its external insulation, this may not be true in all cases. A failure of the non-self-restoring internal insulation is catastrophic and normally leads to the transformer being out of service for a long period, while an external flashover may involve only a short interruption of service without causing lasting damage. Therefore, it may be that, for increased safety, higher test voltages are specified by the purchaser for the internal insulation of the transformer than for the external insulation of other components in the system. When such a distinction is made, the external clearances must be adjusted to fully cover the internal insulation test requirements.

POWER TRANSFORMERS –

Part 3: Insulation levels, dielectric tests and external clearances in air

1 Scope

This International Standard applies to single-phase and three-phase oil-immersed power transformers (including auto-transformers), with the exception of certain small and special transformers, as defined in the scope of IEC 60076-1. It identifies transformer windings to their highest voltage for equipment U_m associated with their corresponding rated insulation levels and details the relevant applicable dielectric tests and minimum external clearances in air between live parts of bushings and to objects at earth potential.

For categories of power transformers and reactors which have their own IEC standards, this standard is applicable only to the extent in which it is specifically called up by cross reference in the other standards.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60076. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 60076 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(421), *International Electrotechnical Vocabulary (IEV) – Chapter 421: Power transformers and reactors*

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60060-2, *High-voltage test techniques – Part 2: Measuring systems*

IEC 60071-1:1993, *Insulation coordination – Part 1: Definitions, principles and rules*

IEC 60071-2:1976, *Insulation coordination – Part 2: Application guide*

IEC 60076-1, *Power transformers – Part 1: General*

IEC 60137:1995, *Bushings for alternating voltages above 1 000 V*

IEC 60270, *Partial discharge measurements*

IEC 60722, *Guide to the lightning impulse and switching impulse testing of power transformers and reactors*

IEC 60790, *Oscilloscopes and peak voltmeters for impulse tests*

IEC 61083-1, *Digital recorders for measurements in high-voltage impulse tests – Part 1: Requirements for digital recorders*

IEC 61083-2, *Digital recorders for measurements in high-voltage impulse tests – Part 2: Evaluation of software used for the determination of the parameters of impulse waveforms*

CISPR 16-1:1993, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1: Radio disturbance and immunity measuring apparatus*

3 Definitions

For the purpose of this part of IEC 60076, the following definitions apply. Other terms used have the meanings ascribed to them in IEC 60076-1 or in IEC 60050(421).

3.1
highest voltage for equipment U_m applicable to a transformer winding
the highest r.m.s. phase-to-phase voltage in a three-phase system for which a transformer winding is designed in respect of its insulation

3.2
rated insulation level
a set of standard withstand voltages which characterize the dielectric strength of the insulation

3.3
standard insulation level
a rated insulation level, the standard withstand voltages of which are associated to U_m as recommended in tables 2 and 3 of IEC 60071-1

3.4
uniform insulation of a transformer winding
the insulation of a transformer winding when all its ends connected to terminals have the same rated insulation level

3.5
non-uniform insulation of a transformer winding
the insulation of a transformer winding when it has a neutral terminal end for direct or indirect connection to earth, and is designed with a lower insulation level than assigned for the line terminal

4 General

The insulation requirements for power transformers and the corresponding insulation tests are given with reference to specific windings and their terminals.

For oil-immersed transformers, the requirements apply to the internal insulation only. Any additional requirements or tests regarding external insulation which are deemed necessary shall be subject to agreement between supplier and purchaser, including type tests on a suitable model of the configuration.

If the purchaser intends to make the connections to the transformer in a way which may reduce the clearances provided by the transformer alone, this should be indicated in the enquiry.

When an oil-immersed transformer is specified for operation at an altitude higher than 1 000 m, clearances shall be designed accordingly. It may then be necessary to select bushings designed for higher insulation levels than those specified for the internal insulation of the transformer windings, see clause 16 of this standard and 4.2 of IEC 60137.

Bushings are subject to separate type and routine tests according to IEC 60137, which verify their phase-to-earth insulation, external as well as internal.

It is presupposed that bushings and tap-changers are specified, designed and tested in accordance with relevant IEC standards. The insulation tests on the complete transformer, however, constitute a check on the correct application and installation of these components.

The insulation test shall generally be made at the supplier's works with the transformer approximately at ambient temperature, but at least at 10 °C.

The transformer shall be completely assembled as in service including supervisory equipment. It is not necessary, however, to fit elements which do not influence the dielectric strength of the internal insulation, for example, the external cooling equipment.

If a transformer fails to meet its test requirements and the fault is in a bushing, it is permissible to replace this bushing temporarily with another bushing and continue the test on the transformer to completion without delay. A particular case arises for tests with partial discharge measurements, where certain types of commonly used high-voltage bushings create difficulties because of their relatively high level of partial discharge in the dielectric. When such bushings are specified by the purchaser, it is permitted to exchange them for bushings of a partial discharge free type during the testing of the transformer, see annex A.

Transformers for cable box connection or direct connection to metal-enclosed SF_6 installations should be designed so that temporary connections can be made for insulation tests, using temporary bushings, if necessary. By agreement, oil/SF_6 bushings may for that reason be replaced by appropriate oil/air bushings.

When the supplier intends to use non-linear elements or surge arresters, built into the transformer or externally fitted, for the limitation of transferred overvoltage transients, this shall be brought to the purchaser's attention at the tender and order stage and it is recommended that it be indicated on the transformer rating plate circuit diagram.

5 Highest voltage for equipment and insulation level

To each winding of a transformer, both for the line and neutral side, is assigned a value of highest voltage for equipment U_m, see 3.1.

The rules for coordination of transformer insulation with respect to transient overvoltages are formulated differently depending on the value of U_m.

When rules about related tests for different windings in a transformer are in conflict, the rule for the winding with the highest U_m value shall apply for the whole transformer.

Rules for a number of special classes of transformers are given in clause 6.

Standardized values of U_m are listed in tables 2 to 4. The value to be used for a transformer winding is the one equal to, or nearest above, the rated value of the winding.

NOTE 1 Single-phase transformers intended for connection in star to form a three-phase bank are designated by phase-to-earth rated voltage, for example 400/ $\sqrt{3}$ kV. The phase-to-phase value determines the choice of U_m in this case, consequently, U_m = 420 kV.

NOTE 2 It may happen that certain tapping voltages are chosen slightly higher than a standardized value of U_m, but that the system to which the winding will be connected has a system highest voltage which stays within the standard value. The insulation requirements are to be coordinated with actual conditions, and therefore this standard value should be accepted as U_m for the transformer, and not the nearest higher value.

NOTE 3 In certain applications with very special conditions the specification of other combinations of withstand voltages may be justified. In such cases, general guidance should be obtained from IEC 60071-1.

NOTE 4 In certain applications, delta-connected windings are earthed through one of the external terminals. In those applications, a higher withstand voltage with respect to the highest voltage for equipment U_m may be required for this winding and should be agreed between supplier and purchaser.

The highest voltage for equipment U_m and its assigned withstand voltages, that is, their insulation level, determine the dielectric characteristics of a transformer. They are verified by a set of dielectric tests depending on U_m, see clause 7.

The value of U_m and the insulation level which are assigned to each winding of a transformer are part of the information to be supplied with an enquiry and with an order. If there is a winding with non-uniform insulation, the assigned U_m and the insulation level of the neutral terminal shall also be specified by the purchaser, see 7.4.3.

The rated withstand voltages for all windings shall appear on the rating plate. The principles of the standard abbreviated notation are shown in some examples below.

The classifications on the insulation design shall independently of the test procedure be derived from the values in table 2, 3 and 4 or from IEC 60071-1. Since in most cases the long-duration induced AC tests are quality control tests in respect to service conditions and not design proving tests, the insulation level shall be characterized as follows:

U_m is the highest voltage for equipment
SI/LI/AC,

where applicable –/LI/AC.

The abbreviations here and in the examples below have the following meaning:

SI is the switching impulse withstand voltage for the line terminals of the winding with the highest U_m;

LI is the lightning impulse withstand voltage for the line and neutral terminals of each individual winding;

AC is the short duration induced and separate source AC withstand voltage for the line and neutral terminals of each individual winding;

h.v. high voltage;

l.v. low voltage;

m.v. medium voltage.

Example 1:

U_m (h.v.) = 72,5 kV and U_m (l.v.) = 12 kV, both uniformly insulated, Y connected

Insulation levels:	h.v. line terminal and neutral	LI/AC	325/140 kV
	l.v. line terminal and neutral	LI/AC	60/28 kV

Example 2:

U_m (h.v.) line = 245 kV, Y connected;

U_m (h.v.) neutral = 52 kV;

U_m (m.v.) line = 72,5 kV, uniform insulation, Y connected;

U_m (l.v.) line = 24 kV, D connected.

Insulation levels:	h.v. line terminal	SI/LI	650/850 kV
	h.v. neutral	LI/AC	250/95 kV
	m.v. line terminal and neutral	LI/AC	325/140 kV
	l.v. line terminal	LI/AC	125/50 kV

Example 3:

Auto-transformer with U_m = 420 kV and 145 kV with an assigned U_m = 17,5 kV for the neutral for direct earth connection, Y connected. U_m (l.v.) line terminal = 24 kV, D connected.

Insulation levels:	h.v. line terminal	SI/LI	1 050/1 300 kV
	m.v. line terminal	LI/AC	550/230 kV
	h.v./m.v.-neutral	LI/AC	–/38 kV
	l.v. line terminal	LI/AC	125/50 kV

or if additionally a short-duration induced test is required:

Insulation levels:	h.v. line terminal	SI/LI/AC	1 050/1 300/570 kV
	m.v. line terminal	LI/AC	550/230 kV
	h.v./m.v. neutral	LI/AC	–/38 kV
	l.v. line terminal	LI/AC	125/50 kV

6 Rules for some particular transformers

In transformers where uniformly insulated windings having different U_m values are connected together within the transformer (usually auto-transformers), the separate source AC withstand test voltages shall be determined by the insulation of the common neutral and its assigned U_m.

In transformers which have one or more non-uniformly insulated windings, the test voltages for the induced withstand voltage test, and for the switching impulse test if used, are determined by the winding with the highest U_m value, and the windings with lower U_m values may not receive their appropriate test voltages. This discrepancy should normally be accepted. If the ratio between the windings is variable by tappings, this should be used to bring the test voltage for the winding with lower U_m voltage as close as possible to the appropriate value.

During switching impulse tests, the voltages developed across different windings are approximately proportional to the ratio of numbers of turns. Rated switching impulse withstand voltages shall only be assigned to the winding with the highest U_m. Test stresses in other windings are also proportional to the ratio of numbers of turns and are adjusted by selecting appropriate tappings to come as close as possible to the assigned value in table 4. The switching impulse test stresses in other windings shall be limited to approximately 80 % of the assigned lightning impulse withstand voltages at these terminals.

Series windings in booster regulating transformers, phase shifting transformers, etc. where the rated voltage of the winding is only a small fraction of the voltage of the system, shall have a value of U_m corresponding to the system voltage. It is often impracticable to test such transformers in formal compliance with this standard, and it should be agreed between the supplier and the purchaser as to which tests have to be omitted or modified.

For single-phase transformers intended to be connected between phases, as in the case of railway traction system supplies, higher test values than indicated in this standard may be necessary.

Special considerations with respect to test connections and number of tests to be performed on multiple re-connectable transformers shall be agreed at the time of placing the order.

7 Insulation requirements and dielectric tests – Basic rules

Transformer windings are identified by their highest voltage for equipment U_m associated to their corresponding insulation levels. This clause details the relevant insulation requirements and applicable dielectric tests. For categories of power transformers and reactors which have their own IEC standards, the requirements are applicable only to the extent in which they are specifically called up by cross reference in the other standards.

7.1 General

The basic rules for insulation requirements and dielectric tests are summarized in table 1.

Levels of standard withstand voltages, identified by the highest voltage for equipment U_m of a winding are given in tables 2, 3 and 4. The choice between the different levels of standard withstand voltages in these tables depends on the severity of overvoltage conditions to be expected in the system and on the importance of the particular installation. Guidance may be obtained from IEC 60071-1.

NOTE 1 Distribution transformers for suburban or rural installation are, in some countries, severely exposed to overvoltages. In such cases, higher test voltages, lightning impulse tests and other tests on individual units may be agreed between supplier and purchaser. They should be clearly stated in the enquiry document.

NOTE 2 Other combinations of U_m may exist in some countries.

Information about the selected transformer insulation requirements and dielectric tests shall be supplied with an enquiry and with an order, see annex C.

The insulation requirements are specified in 7.2. The verification of the withstand voltages by dielectric tests is given in 7.3. The insulation requirements and tests for the neutral terminal of a winding are given in 7.4.

The extension of the lightning impulse test to include impulses chopped on the tail as a special test is recommended in cases where the transformer is directly connected to GIS by means of oil/SF_6 bushings or when the transformer is protected by rod gaps. The peak value of the chopped impulse shall be 10 % higher than for the full impulse.

For transformers with a high-voltage winding having U_m > 72,5 kV, lightning impulse tests are routine tests for all windings of the transformer.

Table 1 – Requirements and tests for different categories of windings

Category of winding	**Highest voltage for equipment U_m** kV	**Tests**				
		Lightning impulse (LI) (see clause 13 and 14)	**Switching impulse (SI)** (see clause 15)	**Long duration AC (ACLD)** (see 12.4)	**Short duration AC (ACSD)** (see 12.2 or 12.3)	**Separate source AC** (see clause 11)
Uniform insulation	$U_m \leq 72{,}5$	Type (note 1)	Not applicable	Not applicable (note 1)	Routine	Routine
Uniform and non-uniform insulation	$72{,}5 < U_m \leq 170$	Routine	Not applicable	Special	Routine	Routine
	$170 < U_m < 300$	Routine	Routine (note 2)	Routine	Special (note 2)	Routine
	$U_m \geq 300$	Routine	Routine	Routine	Special	Routine

NOTE 1 In some countries, for transformers with $U_m \leq 72{,}5$ kV, LI tests are required as routine tests, and ACLD tests are required as routine or type tests.

NOTE 2 If the ACSD test is specified, the SI test is not required. This should be clearly stated in the enquiry document.

7.2 Insulation requirements

The standard dielectric requirements are:

– if applicable in table 1, a standard switching impulse withstand voltage (SI) for the line terminals according to table 4;

– a standard lightning impulse withstand voltage (LI) for the line terminals according to table 2, 3 or 4;

– if specified, a standard impulse withstand voltage (LI) for the neutral terminal; for uniform insulation, the peak value of the impulse voltage being the same as for the line terminals; for non-uniform insulation, the peak value of the impulse voltage as specified in 7.4.3;

– a standard separate source AC withstand voltage according to table 2, 3 or 4;

– if applicable in table 1, a standard short-duration AC induced withstand voltage (ACSD) for the line terminals according to table 2, 3 or 4 and 12.2 or 12.3;

– if applicable in table 1, a long-duration induced AC voltage (ACLD) with partial discharge measurement according to 12.4.

Table 2 – Rated withstand voltages for transformer windings with highest voltage for equipment U_m ≤ 170 kV – Series I based on European practice

Highest voltage for equipment U_m kV r.m.s.	Rated lightning impulse withstand voltage kV peak	Rated short duration induced or separate source AC withstand voltage kV r.m.s.
	20	
3,6		10
	40	
7,2		20
	60	
12		28
	75	
17,5		38
	95	
24		50
	125	
	145	
36		70
	170	
52	250	95
60	280	115
72,5	325	140
	380	150
100		
	450	185
123		
	550	230
145		
	650	275
170		
	750	325

NOTE Dotted lines may require additional phase-to-phase withstand tests to prove that the required phase-to-phase withstand voltages are met.

Low-voltage windings with U_m ≤ 1,1 kV shall be tested with 3 kV separate source AC withstand voltage.

7.3 Dielectric tests

The standard dielectric requirements are verified by dielectric tests. They shall, where applicable and not otherwise agreed upon, be performed in the sequence as given below.

– **Switching impulse test (SI) for the line terminal**, see clause 15

  The test is intended to verify the switching impulse withstand strength of the line terminals and its connected winding(s) to earth and other windings, the withstand strength between phases and along the winding(s) under test.

  The test is an essential requirement for transformers subjected to a long-duration induced AC withstand voltage (ACLD) test.

– **Lightning impulse test (LI) for the line terminals**, see clause 13

  The test is intended to verify the impulse withstand strength of the transformer under test, when the impulse is applied to its line terminals. If the lightning impulse test includes impulses chopped on the tail (LIC), the impulse test is modified according to clause 14.

– **Lightning impulse test (LI) for the neutral terminal**, see 13.3.2

  The test is intended to verify the impulse withstand voltage of the neutral terminal and its connected winding(s) to earth and other windings, and along the winding(s) under test.

  This test is required if a standard impulse withstand voltage for the neutral is specified.

– **Separate source AC withstand voltage test (applied potential test)**, see clause 11

  The test is intended to verify the AC withstand strength of the line and neutral terminals and their connected windings to earth and other windings.

– **Short-duration induced AC withstand voltage test (ACSD)**, see 12.2 and 12.3

  The test is intended to verify the AC withstand strength of each line terminal and its connected winding(s) to earth and other windings, the withstand strength between phases and along the winding(s) under test.

  The test shall be performed in accordance with 12.2 for uniform insulation and 12.3 for non-uniform insulation.

  For U_m > 72,5 kV, the test is normally performed with partial discharge measurements to verify partial discharge free operation of the transformer under operating conditions. By agreement between supplier and purchaser, the partial discharge measurements may also be performed for $U_m \leq 72,5$ kV.

– **Long-duration induced AC voltage test (ACLD)**, see 12.4

  This test is not a design proving test, but a quality control test, and is intended to cover temporary overvoltages and continuous service stress. It verifies partial discharge-free operation of the transformer under operating conditions.

Table 3 – Rated withstand voltages for transformer windings with highest voltage for equipment $U_m \leq 169$ kV – Series II based on North American practice

Highest voltage for equipment U_m kV r.m.s.	**Rated lightning impulse withstand voltage** kV peak		**Rated short-duration induced or separate source AC withstand voltage** kV r.m.s.	
	Distribution (note 1) **and class I transformers** (note 2)	**Class II transformers** (note 3)	**Distribution and class I transformers**	**Class II transformers**
15	95	110	34	34
	125	–	40	–
26,4	150	150	50	50
36,5	200	200	70	70
48,3	250	250	95	95
72,5	350	350	140	140
121		350		140
		450		185
145		550		230
		650		275
169		750		325

NOTE 1 Distribution transformers transfer electrical energy from a primary distribution circuit to a secondary distribution circuit.

NOTE 2 Class I power transformers include high-voltage windings of $U_m \leq 72,5$ kV.

NOTE 3 Class II power transformers include high-voltage windings of $U_m \geq 121$ kV.

Table 4 – Rated withstand voltages for transformer windings with U_m > 170 kV

Highest voltage for equipment U_m kV r.m.s	Rated switching impulse withstand voltage phase-to-earth kV peak	Rated lightning impulse withstand voltage kV peak	Rated short-duration induced or separate source AC withstand voltage kV r.m.s.
		650	
	550		325
		750	
	650		360
245		850	
	750		395
300		950	
	850		460
362		1050	
	950		510
		1175	
		1050	
	850		460
		1175	
	950		510
420		1300	
	1050		570
550		1425	
	1175		630
		1550	
	1300		680
		1675	
	1300		note 3
		1800	
800	1425		note 3
		1950	
	1550		note 3
		2100	

NOTE 1 Dotted lines are not in line with IEC 60071-1 but are current practice in some countries.

NOTE 2 For uniformly insulated transformers with extremely low values of rated AC insulation levels, special measures may have to be taken to perform the short-duration AC induced test, see 12.2.

NOTE 3 Not applicable, unless otherwise agreed.

NOTE 4 For voltages given in the last column, higher test voltages may be required to prove that the required phase-to-phase withstand voltages are met. This is valid for the lower insulation levels assigned to the different U_m in the table.

7.4 Insulation requirements and tests for the neutral terminal of a winding

7.4.1 General

The necessary insulation level depends on whether or not the neutral terminal is intended to be directly earthed, left open or earthed via an impedance. When the neutral terminal is not directly earthed, an overvoltage protective device should be installed between the neutral terminal and earth in order to limit transient voltages.

NOTE The recommendations below deal with the determination of the necessary minimum withstand voltage for the neutral terminal. An increase of the value may sometimes easily be arranged and can improve the interchangeability of the transformer in the system. For non-uniform insulation it may be necessary to design the winding with higher neutral insulation level because of the test connection to be used for the AC withstand test of the transformer, see 12.3.

7.4.2 Directly earthed neutral terminal

The neutral terminal shall be permanently connected to earth, directly or through a current transformer, but without any intentionally added impedance in the connection.

In this case, the separate source AC withstand voltage shall be at least either 38 kV (European practice) or 34 kV (North American practice).

No impulse test on the neutral terminal is recommended. During impulse tests on a line terminal, the neutral shall be connected directly to earth.

7.4.3 Neutral terminal not directly earthed

The neutral terminal is not to be permanently in direct connection to earth. It may be connected to earth through a considerable impedance (for example arc-suppression coil earthing). Separate phase-winding neutral terminals may be connected to a regulating transformer.

It is the responsibility of the purchaser to select the overvoltage protective device, to determine its impulse protection level, and to specify the corresponding impulse withstand voltage for the neutral terminal of the transformer. A suitable U_m shall be assigned for the neutral and shall be selected from table 2, 3 or 4, and the corresponding rated separate source AC withstand voltage from the table shall apply. The AC withstand voltage should be greater than the maximum overvoltage arising under system fault conditions.

The rated impulse withstand voltage of the neutral terminal shall be verified by either of the two tests described in 13.3.2. A chopped wave impulse test on the neutral is not applicable. For transformers having a tapped winding near the neutral end of the winding, the tapping connection with the maximum turns ratio shall be chosen for the impulse test, if not otherwise agreed between purchaser and supplier.

8 Tests on a transformer having a tapped winding

If the tapping range is ±5 % or less, the dielectric tests shall be done with the transformer connected on the principal tapping.

If the tapping range is larger than ±5 %, the choice of tapping cannot be prescribed universally and the following applies.

Testing conditions determine the choice of tapping required for the induced AC test and for the switching impulse test (SI), see clause 6.

Under lightning impulse test (LI) the dielectric stresses are distributed differently depending on the tapping connection and the general design of the transformer. Unless impulse testing on a particular tapping has been agreed, the two extreme tappings and the principal tapping shall be used, one tapping for each of the three individual phases of a three-phase transformer or the three single-phase transformers designed to form a three-phase bank. For an impulse test on the neutral terminal, see 7.4.3.

9 Repeated dielectric tests

For transformers which have already been in service and have been refurbished or serviced, dielectric tests according to 7.2, 7.3 and 7.4 shall be repeated at test levels of 80 % of the original values, unless otherwise agreed upon, and provided that the internal insulation has not been modified. Long-duration AC induced tests (ACLD) according to 12.4 shall always be repeated at 100 % test level.

NOTE The partial discharge criteria should be discussed between the purchaser and supplier depending on the extent of the repair.

Repetition of tests required to prove that new transformers, having been factory tested to 7.2, 7.3 and 7.4, continue to meet the requirements of this standard is always performed at 100 % of test level.

10 Insulation of auxiliary wiring

The wiring for auxiliary power and control circuitry shall be subjected to a 1 min AC separate source test of 2 kV r.m.s. to earth, unless otherwise specified. Motors and other apparatus for auxiliary equipment shall fulfil insulation requirements according to the relevant IEC standard (which are generally lower than the value specified for the wiring alone, and which may sometimes make it necessary to disconnect them in order to test the circuits).

NOTE Auxiliary equipment for large transformers is usually dismantled for shipment. After completion of erection on site, a 1 000 V megaohm meter test is recommended. Any electronic equipment with a withstand voltage less than 1 000 V should be removed prior to this test.

11 Separate source AC withstand voltage test

The separate source AC voltage test shall be made with single-phase alternating voltage as nearly as possible on sine-wave form and not less than 80 % of the rated frequency.

The peak value of voltage shall be measured. The peak value divided by $\sqrt{2}$ shall be equal to the test value.

The test shall commence at a voltage not greater than one-third of the specified test value, and the voltage shall be increased to the test value as rapidly as is consistent with measurement. At the end of the test, the voltage shall be reduced rapidly to less than one-third of the test value before switching off. On windings with non-uniform insulation, the test is carried out with the test voltage specified for the neutral terminal. The line terminals are then subjected to an AC induced withstand voltage test according to 12.3 or 12.4.

The full test voltage shall be applied for 60 s between all terminals of the winding under test connected together and all terminals of the remaining windings, core, frame and tank or casing of the transformer, connected together to earth.

The test is successful if no collapse of the test voltage occurs.

12 Induced AC voltage tests (ACSD, ACLD)

12.1 General

Subclauses 12.2 and 12.3 refer to the short-duration induced AC withstand tests (ACSD) for uniform and non-uniform insulation. For U_m > 72,5 kV, the ACSD test is normally performed with partial discharge measurements. The measurements of partial discharge during the whole application of the test is a valuable tool for the supplier as well as for the purchaser. Measuring partial discharges during the test may indicate an insulation deficiency before breakdown occurs. The test verifies partial discharge-free operation of the transformer during operating conditions.

The requirements for partial discharge measurement during the ACSD test may be omitted. This shall be clearly stated at the enquiry and order stages.

Subclause 12.4 refers to the long-duration induced AC voltage test (ACLD) for uniform and non-uniform insulation. This test is always performed with the measurement of partial discharges during the whole application of the test.

An alternating voltage shall be applied to the terminals of one winding of the transformer. The form of the voltage shall be as nearly as possible sinusoidal and its frequency shall be sufficiently above the rated frequency to avoid excessive magnetizing current during the test.

The peak value of the induced test voltage shall be measured. The peak value divided by $\sqrt{2}$ shall be equal to the test value.

The test time at full test voltage shall be 60 s for any test frequency up to and including twice the rated frequency, unless otherwise specified. When the test frequency exceeds twice the rated frequency, the test time in seconds of the test shall be:

$$120 \times \frac{\text{rated frequency}}{\text{test frequency}}\text{, but not less than 15 s}$$

12.2 Short-duration induced AC withstand voltage test (ACSD) for transformers with uniformly insulated high-voltage windings

All three-phase transformers shall be tested with a symmetrical three-phase supply. If a transformer has a neutral, it should be earthed during the test. On transformers with uniformly insulated windings, only phase-to-phase tests are carried out. Phase-to-earth tests are covered by separate source AC tests according to clause 11.

Dependant on the highest voltage for equipment U_m, the test shall be carried out according to 12.2.1 or 12.2.2.

12.2.1 Transformers with $U_m \leq 72,5$ kV

The phase-to-phase test voltage shall not exceed the rated induced AC withstand voltages in tables 2 or 3. As a rule, the test voltage accross an untapped winding of the transformer shall be as close as possible to twice the rated voltage. Normally, no partial discharge measurements are performed during this test.

The test shall be commenced at a voltage not greater than one-third of the test value and the voltage shall be increased to the test value as rapidly as is consistent with measurement. At the end of the test, the voltage shall be reduced rapidly to less than one-third of the test value before switching off.

The test is successful if no collapse of the test voltage occurs.

12.2.2 Transformers with U_m > 72,5 kV

These transformers shall all, if not otherwise agreed, be tested with partial discharge measurement. The phase-to-phase test voltages shall not exceed the rated AC withstand voltages of tables 2, 3 or 4. As a rule, the test voltage across an untapped winding of the transformer shall be as close as possible to twice the rated voltage.

The partial discharge performance shall be controlled according to the time sequence for the application of the voltage as shown in figure 1.

In order not to exceed the rated withstand voltage between phases according to tables 2, 3 and 4, the partial discharge evaluation level U_2 shall be:

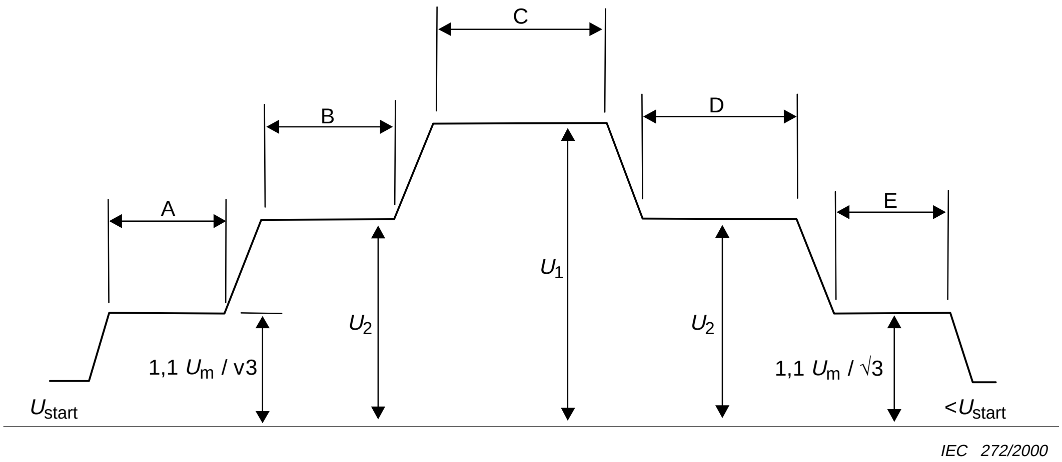
1,3 $U_m / \sqrt{3}$ phase-to-earth and

1,3 U_m phase-to-phase

Annex D, table D.1 shows both the test voltages U_1 obtained from tables 2 or 4 and appropriate values of U_2.

The voltage with respect to earth shall be:

- switched on at a level not higher than one-third of U_2;
- raised to 1,1 $U_m / \sqrt{3}$ and held there for a duration of 5 min;
- raised to U_2 and held there for a duration of 5 min;
- raised to U_1, held there for the test time as stated in 12.1;
- immediately after the test time, reduced without interruption to U_2 and held there for a duration of at least 5 min to measure partial discharges;
- reduced to 1,1 $U_m / \sqrt{3}$ and held there for a duration of 5 min;
- reduced to a value below one-third of U_2 before switching off.



A = 5 min
B = 5 min
C = test time
D ≥ 5 min
E = 5 min

Figure 1 – Time sequence for the application of test voltage with respect to earth

During the raising of the voltage up to a level and reduction from U_2 down again, possible partial discharge inception and partial discharge extinction voltages shall be noted.

The background noise level shall not exceed 100 pC.

NOTE It is recommended that the background noise level should be considerably lower than 100 pC in order to ensure that any inception and extinction of partial discharge can be detected and recorded. The above-mentioned value of 100 pC at 1,1 $U_m / \sqrt{3}$ is a compromise for the acceptance of the test.

The test is successful if

- no collapse of the test voltage occurs;
- the continuous level of ‘apparent charge’ at U_2 during the second 5 min does not exceed 300 pC on all measuring terminals;
- the partial discharge behaviour does not show a continuing rising tendency;
- the continuous level of apparent charges does not exceed 100 pC at 1,1 $U_m/\sqrt{3}$.

A failure to meet the partial discharge criteria shall lead to consultation between purchaser and supplier about further investigations (annex A). In such cases, a long-duration induced AC voltage test (see 12.4) may be performed. If the transformer meets the requirements of 12.4, the test shall be considered successful.

12.3 Short-duration AC withstand voltage test (ACSD) for transformers with non-uniformly insulated high-voltage windings

For three-phase transformers, two sets of tests are required, namely:

a) A phase-to-earth test with rated withstand voltages between phase and earth according to tables 2, 3 or 4 with partial discharge measurement.

b) A phase-to-phase test with earthed neutral and with rated withstand voltages between phases according to tables 2, 3 or 4 with partial discharge measurement. The test shall be carried out in accordance with 12.2.2.

On single-phase transformers, only a phase-to-earth test is required. This test is normally carried out with the neutral terminal earthed. If the ratio between the windings is variable by tappings, this should be used to satisfy test voltage conditions on the different windings simultaneously as far as possible. In exceptional cases, see clause 6, the voltage on the neutral terminal may be raised by connection to an auxiliary booster transformer. In such cases, the neutral should be insulated accordingly.

The test sequence for a three-phase transformer consists of three single-phase applications of test voltage with different points of the winding connected to earth at each time. Recommended test connections which avoid excessive overvoltage between line terminals are shown in figure 2. There are also other possible methods.

Other separate windings shall generally be earthed at the neutral if they are star-connected, and at one of the terminals if they are delta-connected.

The voltage per turn during the test reaches different values depending on the test connection. The choice of a suitable test connection is determined by the characteristics of the transformer with respect to operating conditions or test plant limitations. The test time and the time sequence for the application of test voltage shall be as described in 12.1 and 12.2.2.

For the partial discharge performance evaluation, during the phase-to-phase test, measurements should be taken at U_2 = 1,3 U_m.

NOTE The value U_2 = 1,3 U_m is valid up to U_m = 550 kV with AC test values greater than 510 kV. For U_m = 420 kV and 550 kV with AC test values of 460 kV or 510 kV, the partial discharge evaluation level should be reduced to U_2 = 1,2 U_m in order not to exceed the AC withstand voltages of table 4.

For the three single-phase tests for the phase-to-earth insulation, U_1 is the test voltage according to tables 2, 3 or 4 and U_2 = 1,5 $U_m/\sqrt{3}$. Examples are given in table D.2.

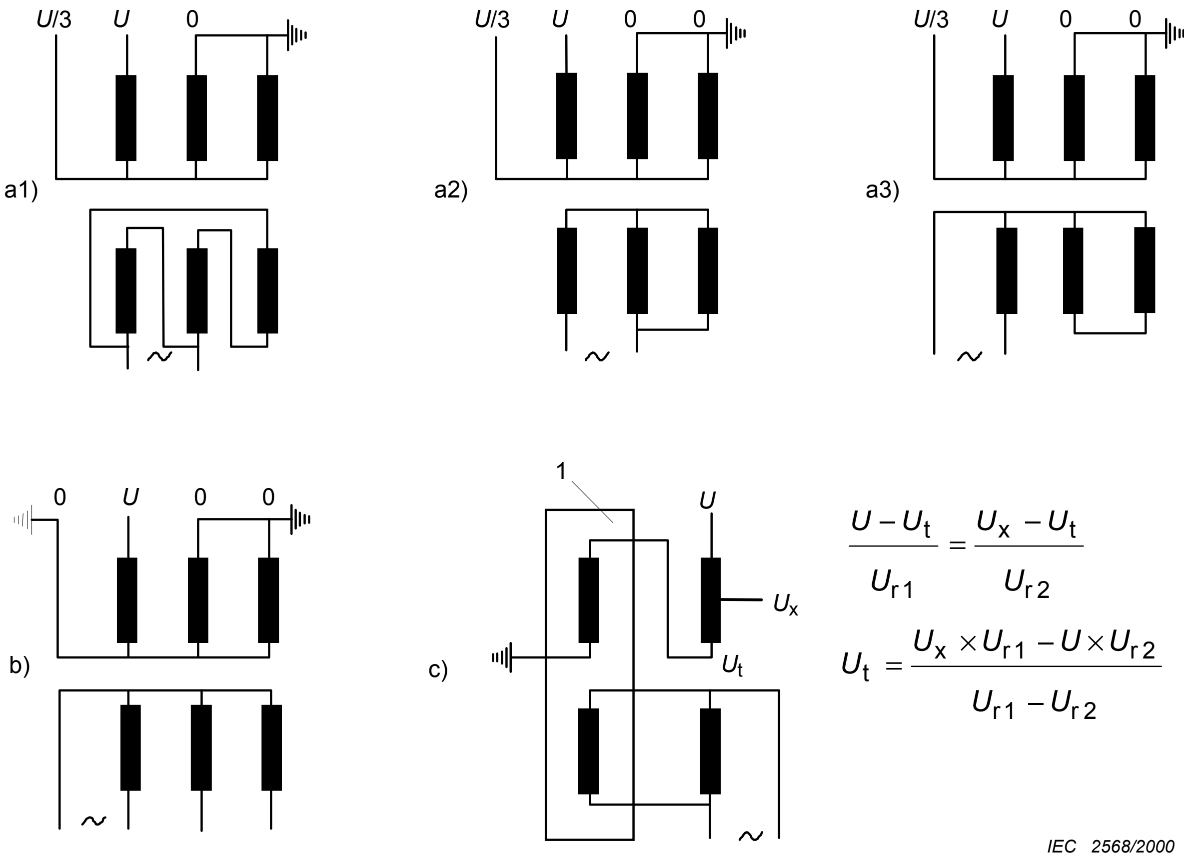
NOTE 1 In the case of transformers with complicated winding arrangements, it is recommended that the complete connection of all windings during the test be reviewed between supplier and purchaser at the contract stage, in order that the test represents a realistic service stress combination as far as possible.

NOTE 2 An additional induced AC withstand test with symmetrical three-phase voltages produces higher stresses between phases. If this test is specified, the clearances between phases should be adjusted accordingly and specified at the contract stage.

NOTE 3 In France, partial discharge measurements during short-duration a.c. test on non-uniform insulated high-voltage windings are not acceptable.

The test is successful if no collapse of the test voltage occurs and if partial discharge measurements fulfil the requirements as stated in 12.2.2 with the following alteration:

The continuous level of ‘apparent charge’ at U_2 during the second 5 min does not exceed 500 pC on all measuring terminals for single-phase tests at $U_2 = 1{,}5\ U_m/\sqrt{3}$ line-to-earth, or 300 pC for phase-to-phase tests at $U_2 = 1{,}3\ U_m$ or as may be required at extremely low a.c. coordination values at $1{,}2\ U_m$.



Key

1 Auxiliary booster transformer

U is the AC test voltage phase-to-earth as stated in table 2, 3 or 4

Figure 2 – Connections for single-phase induced AC withstand voltage tests (ACSD) on transformers with non-uniform insulation

Connection a) may be used when the neutral is designed to withstand at least one-third of the voltage *U*. Three different generator connections to the low-voltage winding are shown. Only a1) is possible if the transformer has unwound magnetic return paths (shell form or five-limb core form).

Connection b) is possible and recommended for three-phase transformers having unwound magnetic return paths for the flux in the tested limb. If there is a delta-connected winding, it has to be open during the test.

Connection c) shows an auxiliary booster transformer, which gives a bias voltage U_t at the neutral terminal of an auto-transformer under test. Rated voltages of the two auto-connected windings are U_{r1}, U_{r2}, and the corresponding test voltages U, U_x. This connection may also be used for a three-phase transformer without unwound magnetic return paths having the neutral insulation designed for less than one-third of the voltage U.

12.4 Long-duration induced AC voltage test (ACLD) with non-uniformly and/or uniformly insulated high-voltage windings, according to table 1

A three-phase transformer shall be tested either phase-by-phase in a single-phase connection that gives voltages on the line terminals according to figure 3, or in a symmetrical three-phase connection. The latter case requires special precautions, see note 1 below.

A three-phase transformer supplied from the low-voltage winding side with a delta-connected high-voltage winding can receive the proper test voltages as described below only in a three-phase test with a floating high-voltage winding. As the voltages with respect to earth in such a test depend fully on the phase capacitances to earth and other windings, this test is not recommended for $U_m \geq 245$ kV in table 1. Any flashover from one of the line terminals to earth can result in major damage of the other two phases due to sudden high voltages. For these kind of transformers, a single-phase connection according to figure 3 is preferred, successively applied to all three phases of a three-phase transformer.

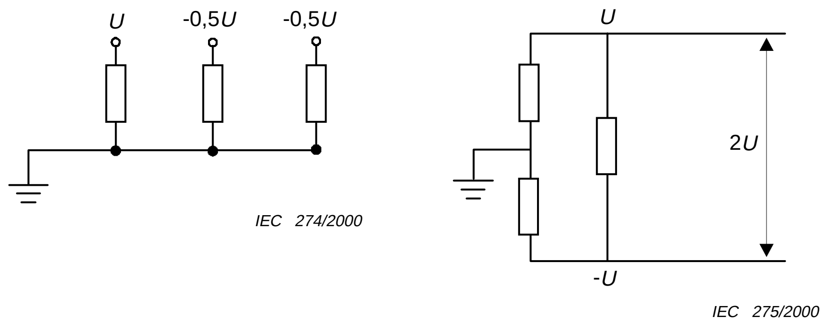
Phase-by-phase testing of delta-connected windings implies double testing of each line terminal and its connected winding. As the test is a quality control test and not a design proving test, the test can be repeated for the line terminal involved without damaging the insulation.

The neutral terminal, if present, of the winding under test shall be earthed. For other separate windings, if they are star-connected they shall be earthed at the neutral, and if they are delta-connected they shall be earthed at one of the terminals or earthed through the neutral of the supplying voltage source. Tapped windings shall be connected to the principal tapping, unless otherwise agreed.

The test arrangement (three-phase or single-phase) shall be agreed between the supplier and purchaser when placing the order.

NOTE 1 If a three-phase star-connected transformer is to be tested in three-phase connection, the test voltage between phases is higher than in the single-phase connection. This may influence the phase-to-phase insulation design and will require larger external clearances.

NOTE 2 If a three-phase delta-connected transformer is to be tested in single-phase connection, the test voltage between phases is higher than in the three-phase connection. This may influence the phase-to-phase insulation design.



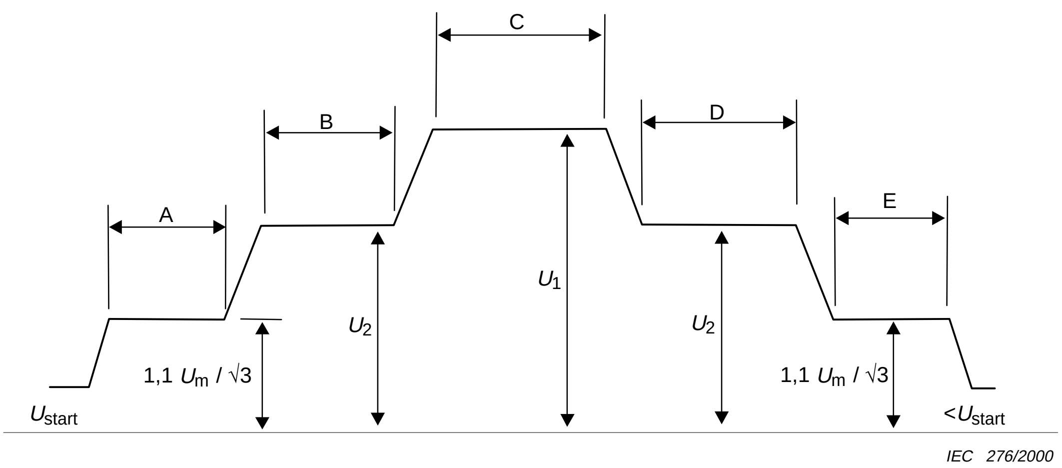
Y- connected **D-connected**

Figure 3 – Phase-by-phase test on Y- or D-connected three-phase transformers

The voltage shall be

- switched on at a level not higher than one-third of U_2;
- raised to 1,1 $U_m / \sqrt{3}$ and held there for a duration of 5 min;
- raised to U_2 and held there for a duration of 5 min;
- raised to U_1, held there for the test time as stated in 12.1;
- immediately after the test time, reduced without interruption to U_2 and held there for a duration of at least 60 min when $U_m \geq 300$ kV or 30 min for $U_m < 300$ kV to measure partial discharges;
- reduced to 1,1 $U_m / \sqrt{3}$ and held there for a duration of 5 min;
- reduced to a value below one-third of U_2 before switching off.

The duration of the test, except for the enhancement level U_1, shall be independent of the test frequency.



A = 5 min
B = 5 min
C = test time
D = 60 min for $U_m \geq 300$ kV or 30 min for $U_m < 300$ kV
E = 5 min

Figure 4 – Time sequence for the application of test voltage for induced AC long-duration tests (ACLD)

During the whole application of the test voltage, partial discharges shall be monitored.

The voltages to earth shall be:

$U_1 = 1{,}7\ U_m / \sqrt{3}$

$U_2 = 1{,}5\ U_m / \sqrt{3}$

NOTE For network conditions where transformers are severely exposed to overvoltages, values for U_1 and U_2 can be 1,8 $U_m / \sqrt{3}$ and 1,6 $U_m / \sqrt{3}$ respectively. This requirement shall be clearly stated in the enquiry.

The background noise level shall not exceed 100 pC.

NOTE It is recommended that the background noise level should be considerably lower than 100 pC in order to insure that any inception and extinction of partial discharges can be detected and recorded. The above-mentioned value of 100 pC at 1,1 $U_m / \sqrt{3}$ is a compromise for the acceptance of the test.

The partial discharges shall be observed and evaluated as follows. Further information may be obtained from annex A, which, in turn, refers to IEC 60270.

- Measurements shall be carried out at the line terminals of all non-uniformly insulated windings, which means that the higher and lower voltage line terminals of an auto-connected pair of windings will be measured simultaneously.
- The measuring channel from each terminal used shall be calibrated with repetitive impulses between the terminal and earth, and this calibration is used for the evaluation of readings during the test. The apparent charge measured at a specific terminal of the transformer, using the appropriate calibration, shall refer to the highest steady-state repetitive impulses. Occasional bursts of high partial discharge level should be disregarded. Continuous discharges for any length of time occurring at irregular intervals can be accepted up to 500 pC, provided there is no steadily increasing tendency.
- Before and after the application of test voltage, the background noise level shall be recorded on all measuring channels.
- During the raising of voltage up to level U_2 and reduction from U_2 down again, possible inception and extinction voltages should be noted. Measurement of the apparent charge shall be taken at 1,1 $U_m / \sqrt{3}$.
- A reading shall be taken and noted during the first period at voltage U_2. No apparent charge values are specified for this period.
- No values of apparent charge are assigned to the application of U_1.
- During the whole of the second period at voltage U_2, the partial discharge level shall be continuously observed and readings shall be recorded every 5 min.

The test is successful if

- no collapse of the test voltage occurs;
- the continuous level of partial discharges does not exceed 500 pC during the long duration test at U_2;
- the partial discharge behaviour shows no continuously rising tendency at U_2. Occasional high bursts of non-sustained nature should be disregarded;

  NOTE North American practice limits the allowable change during the test to 150 pC to recognize possible internal problems.

- the continuous level of apparent charges does not exceed 100 pC at 1,1 $U_m / \sqrt{3}$.

As long as no breakdown occurs, and unless very high partial discharges are sustained for a long time, the test is regarded as non-destructive. A failure to meet the partial discharge acceptance criteria shall therefore not warrant immediate rejection, but lead to consultation between purchaser and supplier about further investigations. Suggestions for such procedures are given in annex A.

Concerning difficulties with bushings during the test, see also clause 4.

13 Lightning impulse (LI) test

13.1 General

When required, lightning impulse (LI) tests shall only be made on windings that have terminals brought out through the transformer tank or cover.

General definitions of terms related to impulse tests, requirements for test circuits, performance tests and routine checks on approved measuring devices may be found in IEC 60060-1. Further information is given in IEC 60722.

For oil-immersed transformers, the test voltage is normally of negative polarity, because this reduces the risk of erratic external flashovers in the test circuit.

Bushing spark gaps may be removed or their spacing increased to prevent sparkover during the test.

When non-linear elements or surge diverters – built into the transformer or external – are installed for the limitation of transferred overvoltage transients, the impulse test procedure shall be discussed in advance for each particular case. If such elements are present during the test, the evaluation of test records (see 13.5) may be different compared to the normal impulse test. By their very nature, non-linear protective devices connected across the windings may cause differences between the reduced full wave and the full-wave impulse oscillograms. To prove that these differences are indeed caused by operation of these devices this, should be demonstrated by making two or more reduced full-wave impulse tests at different voltage levels to show the trend in their operation. To show the reversibility of any non-linear effects, the same reduced full-wave impulses shall follow up the full-wave test voltage in a reversed way.

EXAMPLE 60 %, 80 %, 100 %, 80 %, 60 %.

The test impulse shall be a full standard lightning impulse: 1,2 μs ± 30 %/50 μs ± 20 %.

There are cases, however, where this standard impulse shape cannot reasonably be obtained, because of low winding inductance or high capacitance to earth. The resulting impulse shape is then often oscillatory. Wider tolerances may, in such cases, be accepted by agreement between purchaser and supplier. See IEC 60722.

The impulse shape problem may also be treated by alternative methods of earthing during the test, see 13.3.

The impulse circuit and measuring connections shall remain unchanged during calibration and full voltage tests.

NOTE The information given in IEC 60722 with reference to waveshape evaluation is based on oscilloscopic records, engineering rules and eye evaluation of waveshape parameters. With the application of digital recorders according to IEC 61083-1 and IEC 61083-2 in high-voltage impulse testing of power transformers, a clear warning with respect to amplitude and time parameters should be given with respect to the evaluation of non-standard waveshapes.

In particular, when testing high power rated low-voltage windings with resulting unipolar overshoots with frequencies less than 0,5 MHz, IEC 61083-2 is not applicable for the amplitude evaluation of such non-standard waveshapes. Errors in excess of 10 % have been observed due to the built-in curve smoothing algorithms in the digitizers.

In such cases, careful evaluation of the raw data plots using engineering judgement is needed. A parallel measurement of the peak voltage by a peak voltmeter according to IEC 60790 is highly recommended.

13.2 Test sequence

The test sequence shall consist of one impulse of a voltage between 50 % and 75 % of the full test voltage, and three subsequent impulses at full voltage. If, during any of these applications, an external flashover in the circuit or across a bushing spark gap should occur, or if the oscillographic recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made.

NOTE Additional impulses at amplitudes not higher than 50 % may be used but need not be shown in the test report.

13.3 Test connections

13.3.1 Test connections during tests on line terminals

The impulse test sequence is applied to each of the line terminals of the tested winding in succession. In the case of a three-phase transformer, the other line terminals of the winding shall be earthed directly or through a low impedance, not exceeding the surge impedance of the connected line.

If the winding has a neutral terminal, the neutral shall be earthed directly or through a low impedance such as a current measuring shunt. The tank shall be earthed.

In the case of a separate winding transformer, terminals of windings not under test are likewise earthed directly or through impedances, so that in all circumstances, the voltage appearing at the terminals is limited to not more than 75 % of their rated lightning impulse withstand voltage for star-connected windings, and 50 % for delta-connected windings.

In the case of an auto-transformer, when testing the line terminals of the high-voltage winding, it may happen that the standard impulse wave-form cannot reasonably be obtained if the line terminals of the common winding are earthed directly or through a current measuring shunt. The same applies to the testing of the line terminals of the common winding if the line terminals of the high-voltage winding are earthed. It is then permissible to earth the non-tested line terminals through resistors not exceeding 400 Ω. Furthermore, the voltages appearing on the non-tested line terminals to earth should not exceed 75 % of their rated lightning impulse withstand voltage for star-connected windings and 50 % for delta-connected windings.

When impulse testing windings with low impedances, it may be difficult to obtain correct impulse shape on the tested terminals. In this case wider tolerances have to be accepted, see 13.1. It is also possible to simplify the problem by earthing the non-tested terminals of the tested phase through resistors. The resistance value shall be chosen so that the voltage appearing on the terminals is limited to not more than 75 % of their rated lightning impulse withstand voltage for star-connected windings or 50 % for delta connected windings. Alternatively, by agreement at the time of placing the order the transferred surge method may be employed, see 13.3.3.

Exceptions from this main procedure are given in 13.3.2 and 13.3.3.

13.3.2 Impulse test on a neutral terminal

When the neutral terminal of a winding has a rated impulse withstand voltage, it may be verified by a test as follows:

a) by indirect application:

   Test impulses are applied to any one of the line terminals or to all three line terminals of a three-phase winding connected together. The neutral terminal is connected to earth through an impedance or is left open, and the voltage amplitude developed across this impedance or to earth, when a standard lightning impulse is applied to the line terminal, shall be equal to the rated withstand voltage of the neutral terminal. No prescriptions are given for the shape of the resulting impulse across the impedance. The amplitude of the impulse applied to the line terminal is not prescribed, but shall not exceed 75 % of the rated lightning impulse withstand voltage of the line terminal.

b) by direct application:

   Test impulses corresponding to the rated withstand voltage of the neutral are applied directly to the neutral with all line terminals earthed. In this case, however, a longer duration of the front time is allowed, up to 13 µs.

13.3.3 The transferred surge method on low-voltage windings

When the low-voltage winding cannot be subjected to lightning overvoltages from the low-voltage system, this winding may, by agreement between supplier and purchaser, be impulse tested with surges transferred from the high-voltage winding.

This method is also to be preferred when the design is such that an impulse directly applied to the low-voltage winding could result in unrealistic stressing of higher voltage windings, particularly when there is a large tapping winding physically adjacent to the low-voltage winding.

With the transferred surge method, the tests on the low-voltage winding are carried out by applying the impulses to the adjacent higher voltage winding. The line terminals of the low-voltage winding are connected to earth through resistances of such value that the amplitude of transferred impulse voltage between line terminals and earth, or between different line terminals or across a phase winding, will be as high as possible but not exceeding the rated impulse withstand voltage. The magnitude of the applied impulses shall not exceed the impulse level of the winding to which the impulses are applied.

The details of the procedure shall be agreed before the test.

13.4 Records of test

The oscillographic or digital records obtained during calibrations and tests shall clearly show the applied voltage impulse shape (front time, time-to-half value and amplitude).

At least one more measurement channel shall be used. In most cases an oscillogram of the current flowing to earth from the tested winding (neutral current) or the capacitive probe current, i.e. the current transferred to the non-tested and shorted winding, will represent the best sensitivity for fault indication. The current flowing from tank to earth, or the transferred voltage in a non-tested winding, are examples of alternative suitable measuring quantities. The detection method chosen shall be agreed between supplier and purchaser.

Further recommendations about failure detection, suitable time-base durations, etc. are given in IEC 60722.

13.5 Test criteria

The absence of significant differences between voltage and current transients recorded at reduced voltage and those recorded at full test voltage constitutes evidence that the insulation has withstood the test.

The detailed interpretation of the oscillographic or digital test records and discrimination of marginal disturbances from true records of failure require a great deal of skill and experience. Further information is given in IEC 60722.

If there is doubt about the interpretation of possible discrepancies between oscillograms or digital records, three subsequent impulses at full voltage shall be applied, or the whole impulse test on the terminal shall be repeated. The test shall be considered successfully passed if no further and progressive deviations are observed.

Additional observations during the test (abnormal sound effects, etc.) may be used to confirm the interpretation of the oscillographic or digital records, but they do not constitute evidence in themselves.

Any difference in the wave shape between the reduced full wave and final full wave detected by comparison of the two current oscillograms may be indication of failure or deviations due to non-injurious causes. They should be fully investigated and explained by a new reduced wave and full-wave test. Examples of possible causes of different wave shapes are operation of protective devices, core saturation, or conditions in the test circuit external to the transformer.

14 Test with lightning impulse chopped on the tail (LIC)

14.1 General

The test is a special test and should be used for special applications on line terminals of a winding. When it has been agreed to make this test, it shall be combined with the full lightning impulse test in the manner described below. The peak value of the chopped impulse shall be 1,1 times the amplitude of full impulse.

Usually, the same settings of the impulse generator and measuring equipment are used, and only the chopping gap equipment is added. The standard chopped lightning impulse shall have a time to chopping between 2 µs and 6 µs.

Different time bases may be used to record lightning impulses chopped on the tail.

14.2 Chopping gap and characteristics of the chopping

It is recommended to use a triggered-type chopping gap with adjustable timing, although a plain rod-rod gap is allowed. The chopping circuit shall be so arranged that the amount of overswing to opposite polarity of the recorded impulse will be limited to not more than 30 % of the amplitude of the chopped impulse; the insertion of an impedance *Z* in the chopped circuit is usually necessary to maintain this limit.

14.3 Test sequence and test criteria

As indicated above, the test is combined with the full impulse test in a single sequence. The recommended order of the different impulse applications is:

– one reduced level full impulse;
– one full level full impulse;
– one or more reduced level chopped impulse(s);
– two full level chopped impulses;
– two full level full impulses.

The same types of measuring channels and oscillographic or digital records are specified as for the full-wave impulse test.

In principle, the detection of faults during a chopped impulse test depends essentially on a comparison of the oscillographic or digital records of the full level and reduced level chopped impulses. The neutral current record (or any other supplementary recording) presents a superposition of transient phenomena due to the front of the original impulse and from the chopping. Account should therefore be taken of the possible variations, even slight, of the chopping time delay. The later part of the oscillation pattern is then modified, and this effect is difficult to separate from the record of a fault. Frequency changes after the chopping, however, need to be clarified.

The recordings of successive full impulse tests at full level constitute a supplementary criterion of a fault, but they do not constitute in themselves a quality criterion for the chopped impulse test.

15 Switching impulse test (SI)

15.1 General

General definitions of terms related to impulse tests, requirements on test circuits, performance tests and routine checks on approved measuring devices, may be found in IEC 60060-1. Further information is given in IEC 60722.

The impulses are applied either directly from the impulse voltage source to a line terminal of the winding under test, or to a lower voltage winding so that the test voltage is inductively transferred to the winding under test. The specified test voltage shall appear between line and earth. Neutral terminals shall be earthed. In a three-phase transformer, the voltage developed between line terminals during the test shall be approximately 1,5 times the voltage between line and neutral terminals, see 15.3.

The test voltage is normally of negative polarity to reduce the risk of erratic external flashover in the test circuit.

The voltages developed across different windings of the transformer are approximately proportional to the ratio of numbers of turns and the test voltage will be determined by the winding with the highest U_m value, see clause 6.

The voltage impulse shall have a virtual front time of at least 100 µs, a time above 90 % of the specified amplitude of at least 200 µs, and a total duration from the virtual origin to the first zero passage at least 500 µs but preferably 1 000 µs.

NOTE The impulse wave shape is purposely different from the standard waveshape of 250/2 500 µs recommended in IEC 60060-1, since IEC 60060-1 is valid for non-saturable magnetic circuit equipment.

The front time shall be selected by the supplier so that the voltage distribution along the winding under test will be essentially linear. Its value is usually greater than 100 µs but less than 250 µs. During the test considerable flux is developed in the magnetic circuit. The impulse voltage can be sustained up to the instant when the core reaches saturation and the magnetizing impedance of the transformer becomes drastically reduced.

The maximum possible impulse duration can be increased by introducing remanence of opposite polarity before each full-voltage test impulse. This is accomplished by lower voltage impulses of similar shape but opposite polarity. See IEC 60722.

Advice for the selection of tap position is given in clause 8.

15.2 Test sequence and records

The test sequence shall consist of one impulse (calibration impulse) of a voltage between 50 % and 75 % of the full test voltage and three subsequent impulses at full voltage. If the oscillographic or digital recording should fail, that application shall be disregarded and a further application made. Oscillographic or digital records shall be obtained of at least the impulse wave-shape on the line terminal under test and preferably the neutral current.

NOTE Due to the influence of magnetic saturation on impulse duration, successive oscillograms are different and reduced and full level test recordings are not identical. To limit this influence, after each test impulse at identical test levels, demagnetizing impulses at reduced level of opposite polarity are required.

15.3 Test connections

During the test the transformer shall be in a no-load condition. Windings not used for the test shall be solidly earthed at one point but not short-circuited. For a single-phase transformer, the neutral terminal of the tested winding shall be solidly earthed.

A three-phase winding shall be tested phase by phase with the neutral terminal earthed and with the transformer so connected that a voltage of opposite polarity and about half amplitude appears on the two remaining line terminals which may be connected together.

To limit the voltage of opposite polarity to approximately 50 % of the applied level, it is recommended to connect high ohmic damping resistors (10 kΩ to 20 kΩ) to earth at the non-tested phase terminals.

Bushing spark gaps and additional means for limitation of overvoltages are treated as specified for the lightning impulse test, see 13.1.

15.4 Test criteria

The test is successful if there is no sudden collapse of voltage or discontinuity of the neutral current indicated on the oscillographic or digital records.

Additional observations during the test (abnormal sound effects, etc.) may be used to confirm the oscillographic records, but they do not constitute evidence in themselves.

16 External clearances in air

16.1 General

Clearances in air are understood as distances where the electrostatic field is free of disturbance by insulator bodies. This standard does not deal with the requirements of effective flashover distance or creepage distance along the bushing insulators nor does it consider the risk from intrusion of birds and other animals.

When establishing the requirements of the present standard in the higher voltage ranges, it has been recognized that the bushing ends have normally rounded electrode shapes.

The clearance requirements are valid between such rounded electrodes. It is assumed that conductor clamps with their associated shield electrodes are suitably shaped so that they do not reduce the flashover voltage. It is also assumed that the arrangement of incoming conductors does not reduce the effective clearances provided by the transformer itself.

NOTE If the purchaser intends to make his connection in a particular way which is likely to reduce the effective clearances, this should be mentioned in the enquiry.

In general, the provision of adequate clearances in air becomes technically difficult mainly at high system voltages, particularly for relatively small units, or when the installation space is restricted. The principle followed in this standard is to provide minimum, non-critical clearances which are satisfactory without further discussion or proof under various system conditions and in different climates. Other clearances based on past or current practice shall be subject to agreement between purchaser and supplier.

The recommended clearances are referred to the rated withstand voltages of the internal insulation of the transformer, unless otherwise specified in the enquiry and order. When the clearances of the transformer are equal to or larger than the values specified in this standard and the bushings have properly selected ratings according to IEC 60137, then the external insulation of the transformer shall be regarded as satisfactory without further testing.

NOTE 1 The impulse withstand strength of the external insulation is polarity dependant, in contrast to what is assumed for the internal insulation. The tests prescribed for the internal insulation of the transformer do not automatically verify that the external insulation is satisfactory. The recommended clearances are dimensioned for the more onerous polarity (positive).

NOTE 2 It is recognized that in some countries, clearances may be different if based on LI and AC withstand voltages only.

NOTE 3 If a clearance smaller than that according to the paragraph above has been used for a contract, a type test may be required on an arrangement simulating the actual clearance, or on the transformer itself. Recommended test procedures for such cases are given.

If the transformer is specified for operation at an altitude higher than 1 000 m, the clearance requirements shall be increased by 1 % for every 100 m by which the altitude exceeds 1 000 m.

Requirements are given for the following clearances:

– clearance phase-to-earth and phase-to-neutral;
– clearance phase-to-phase between phases of the same winding;
– clearance between a line terminal of the high voltage winding and a line terminal of a lower voltage winding.

It follows from the above that the recommended values are in effect minimum values. The design clearances shall be stated on the outline drawing. These are nominal values subject to normal manufacturing tolerances and they have to be selected so that the actual clearances will be at least equal to the specified values.

These statements shall be taken as proof that the transformer complies with the recommendations of this standard, or with the modified values which may have been agreed for the particular contract.

16.2 Bushing clearance requirements as determined by transformer insulation withstand voltages

The requirements are formulated as described below, depending on the U_m voltage value of the winding.

16.2.1 $U_m \leq 170$ kV

The same distance shall apply for clearances phase-to-earth, phase-to-neutral, phase-to-phase, and towards terminals of a lower voltage winding.

The recommended minimum clearances are given in tables 5 and 6 with reference to the rated withstand voltages which appear in tables 2 and 3.

If a type test on a reduced clearance is to be conducted this shall be a lightning impulse test, dry, with positive impulse, three shots, with the test voltage according to tables 5 or 6 respectively.

NOTE As indicated in table 2, some low lightning impulse withstand values can be specified according to IEC 60071-1. A check whether this condition requires a larger phase-to-phase clearance should be made.

16.2.2 U_m > 170 kV

For equipment with U_m > 170 kV where switching impulse testing is specified, the recommended clearances are given in table 7.

It is assumed that the requirements for external insulation are the same irrespective of the performance of the short-duration AC withstand voltage test according to the values given in table 4.

The internal insulation is verified by a switching impulse test with negative test voltage on the tested phase, and with approximately 1,5 times the test voltage between the phases on three-phase transformers, see IEC 60071-1.

For the external insulation the phase-to-phase withstand voltage is defined differently. An appropriate test procedure involves positive polarity impulses for a configuration phase-to-earth, and opposite polarity impulses for phase-to-phase clearances, see 16.2.2.3. This has been considered for the clearance values given in table 7.

16.2.2.1 Clearance phase-to-earth, phase-to-neutral, and phase-to-phase between phases of the same winding

The clearance from the high-voltage bushing top to earth (tank, conservator, cooling equipment, switchyard structures, etc.) or to the neutral terminal is determined from column 4 of table 7.

The clearance between bushing caps of different phases is determined from column 5 of table 7.

16.2.2.2 Clearance between terminals of different windings

The clearance between terminals of different windings of the transformer shall be checked with regard to both switching impulse and lightning impulse conditions.

The switching impulse withstand requirement is based on the calculated voltage difference which appears between the two terminals, see clause 15. This voltage difference determines the required clearance with regard to the switching impulse condition. Figure 6 is used to find the recommended clearance if the terminals receive opposite polarity voltages and the ratio between the appearing voltages is 2 or less. In other cases, figure 5 applies.

NOTE If figures 5 and 6 are compared, it appears that a phase-to-phase clearance withstands a higher voltage difference than the same distance would do in a phase-to-earth configuration. The reason is that in the phase-to-phase configuration the two terminals are supposed to have opposite polarity, and the maximum dielectric gradient at either of them (which is largely determined by the voltage to earth) is relatively lower. It is assumed also that the electrodes have a rounded shape.

The clearance shall, however, also fulfil the lightning impulse withstand requirement, which pre-supposes that the lower voltage winding terminal is at earth potential when rated lightning impulse withstand voltage is applied to the high-voltage terminal. The distance requirement in column 6 of table 7 and figure 7, corresponding to this rated lightning impulse voltage, has therefore to be fulfilled between the two terminals. The higher of the two clearance requirements shall apply.

The switching impulse test on three-phase transformers will induce voltages between phases of other star-connected windings as well. It shall be checked whether this condition requires a larger phase-to-phase clearance in such a winding than as prescribed for this winding alone such as in 16.2.1.

16.2.2.3 Type test procedure

If a type test on a reduced clearance is to be conducted, the test procedure shall be as follows.

A test on a configuration phase-to-earth (or phase-to-neutral, or towards a terminal of a lower voltage winding) shall consist of a switching impulse test, dry, with positive polarity on the line terminal of the winding (the higher voltage winding). The counter electrode shall be earthed. If the tested terminal belongs to a three-phase winding, the other line terminals shall also be earthed.

NOTE This test is not generally feasible on complete three-phase transformers and may therefore have to be conducted on a model simulating the actual configuration of the transformer.

Tests on the phase-to-phase clearances of a three-phase transformer shall consist of switching impulse tests, dry, with half of the specified test voltage, positive, on one line terminal, the other half, negative, on another line terminal, and the third line terminal earthed.

The combinations of phase-to-earth and phase-to-phase test voltages are reproduced in table 7.

When the outer phases are placed symmetrically with respect to the middle phase, it is sufficient to make two separate tests, one with positive polarity on the middle phase, an outer phase having negative polarity and the other with positive polarity on an outer phase, the middle phase having negative polarity. If the line terminal arrangement is asymmetrical, it may be necessary to perform more than two tests.

Each test shall consist of 15 applications of impulse voltage with a wave shape 250/2 500 μs in accordance with IEC 60060-2.

NOTE The above test procedure for phase-to-phase external clearances, differs in several respects from the switching impulse test procedure specified for the internal insulation of the transformer in clause 14. The two test procedures do not replace each other.

Table 5 – Recommended minimum clearances phase-to earth, phase-to-phase, phase-to-neutral and to lower voltage windings from bushing live parts on power transformers having windings with highest voltage for equipment $U_m \leq 170$ kV – Series I based on European practice

Highest voltage for equipment U_m kV r.m.s	Rated lightning impulse withstand voltage kV peak	Minimum clearance mm
	20	-
3,6		
	40	60
7,2		
	60	90
12		
	75	110
17,5		
	95	170
24		
	125	210
36	145	275
52	170	280
72,5	250	450
100	325	630
123	450	830
145	550	900
170	650	1250
	750	1450

Table 6 – Recommended minimum clearances phase-to-earth, phase-to-phase, phase-to-neutral and to lower voltage windings from bushing live parts on power transformers having windings with highest voltage for equipment $U_m \leq 169$ kV – Series II based on North American practice

Highest voltage for equipment U_m kV r.m.s.	Rated lightning impulse withstand voltage kV peak	Minimum clearance mm
	60 (see note)	65 (see note)
<15	75	100
	95 (see note)	140 (see note)
	110	165
26,4	150	225
36,5	200	330
48,3	250	450
72,5	350	630
121	450	830
145	550	1 050
169	650	1 250
	750	1 450

NOTE Indicates value for distribution transformers only.

Table 7 – Recommended minimum clearances phase-to-earth, phase-to-phase, phase-to-neutral and to lower voltage windings from bushing live parts on power transformers having windings with highest voltage for equipment U_m > 170 kV

Highest voltage for equipment U_m kV r.m.s.	Rated switching impulse withstand voltage kV peak	Rated lightning impulse withstand kV peak	Minimum clearances		
			Phase-to-earth mm (note 1)	Phase-to-phase mm (note 1)	To other winding mm (note 2)
		650			1 250
	550		1 250	1 450	
		750			1 450
245	650		1 500	1 800	
		850			1 600
300	750		1 900	2 250	
		950			1 750
362	850		2 300	2 650	
		1 050			1 950
	950		2 700	3 100	
		1 175			2 200
		1 050			1 950
	850		2 300	2 650	
		1 175			2 200
	950		2 700	3 100	
420		1 300			2 400
	1 050		3 100	3 500	
		1 425			2 650
550	1 175		3 700	4 200	
		1 550			2 850
	1 300		4 400	5 000	
		1 675			3 100
	1 300		4 400	5 000	
		1 800			3 300
800	1 425		5 000	5 800	
		1 950			3 600
	1 550		5 800	6 700	
		2 100			3 800

NOTE 1 Based on switching impulse withstand voltage.

NOTE 2 Based on lightning impulse withstand voltage, see also 16.2.2.

NOTE 3 Clearances may be different if based on LI and AC withstand voltages only.

NOTE 4 Dotted lines are not in conformance with IEC 60071-1 but are current practice in some countries.

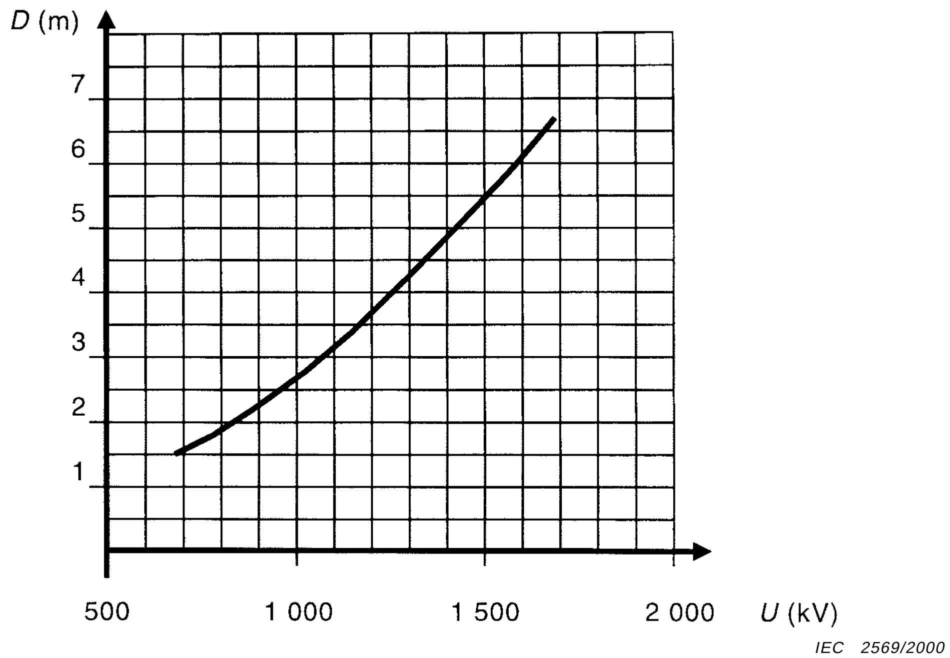


Figure 5 – Clearance phase-to-earth based on rated switching impulse withstand voltage

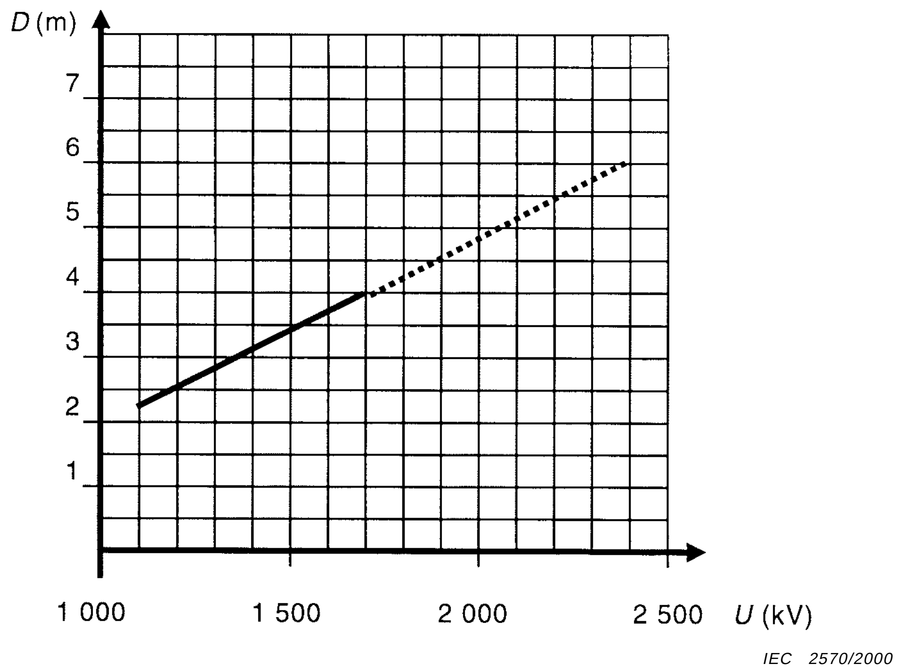


Figure 6 – Clearance phase-to-phase based on switching impulse voltage appearing between phases

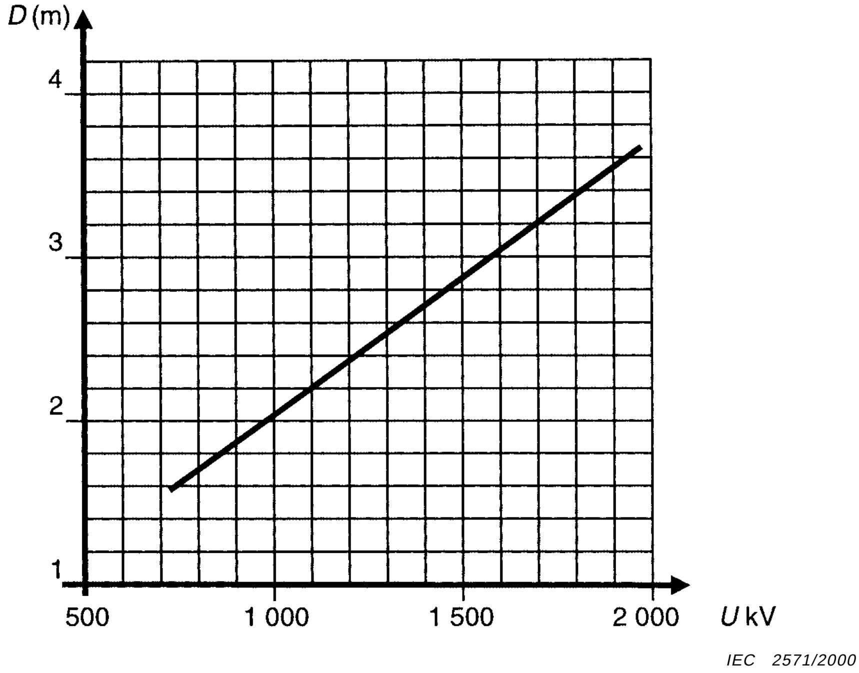


Figure 7 – Clearance based on lightning impulse voltage

Annex A
(informative)

Application guide for partial discharge measurements during induced a.c. withstand voltage test on transformers according to 12.2, 12.3 and 12.4

A.1 Introduction

A partial discharge (p.d.) is an electric discharge that only partially bridges the insulation between conductors. In a transformer, such a partial discharge causes a transient change of the voltage to earth at every externally available winding terminal.

Measuring impedances are connected effectively between the earthed tank and the terminals, usually through a bushing tap or through a separate coupling capacitor, as detailed in clause A.2.

The actual charge transferred at the site of a partial discharge cannot be measured directly. The preferred measuring partial discharge activities on power transformers is the determination of the apparent charge q as defined in IEC 60270.

The apparent charge q related to any measuring terminal is determined by a suitable calibration, see clause A.2.

A particular partial discharge gives rise to different values of apparent charge at different terminals of the transformer. The comparison of simultaneously collected indications at different terminals may give information about the location of the partial discharge source within the transformer, see clause A.5.

The acceptance test procedures specified in 12.2, 12.3 and 12.4 call for measurement of apparent charge at the winding line terminals.

A.2 Connection of measuring and calibration circuits – Calibration procedure

The measuring equipment is connected to the terminals by matched coaxial cables. The measuring impedance is, in its simplest form, the matching impedance of the cable, which may in turn be the input impedance of the measuring instrument.

In order to improve the signal-to-noise ratio of the complete measuring system, it may be convenient to make use of tuned circuits, pulse transformers, and amplifiers between the test object terminals and the cable.

The circuit should represent a reasonably constant resistance, when viewed from the test object terminals, throughout the frequency range used for the partial discharge measurements.

During the measurement of partial discharge between a line terminal of a winding and the earthed tank, the preferred arrangement is to install the measuring impedance Z_m effectively between the value of the capacitance graded bushing tap and the earthed flange, see figure A.1. If a capacitance tap is not provided, it is also possible to insulate the bushing flange from the tank and use it as the measuring terminal. The equivalent capacitances between the central conductor, the measuring terminal and earth, act as an attenuator for the partial discharge signal. This is, however, covered by the calibration which takes place between the top terminal of the bushing and earth.

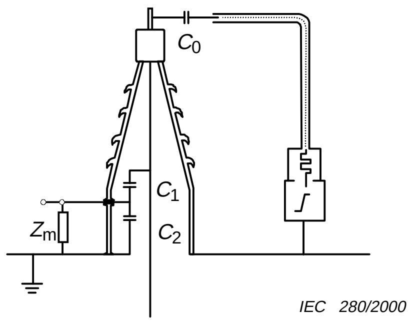


Figure A.1 – Calibration circuit for partial discharge measurement when the value of the capacitance graded bushing is available

If measurements have to be taken at a live terminal without any available value of the capacitance graded bushing tap (or insulated flange), the method with a high-voltage coupling capacitor is used. A partial discharge free capacitor is required and its capacitance value C should be suitably large in comparison with the calibration generator capacitance C_0. The measuring impedance (with a protective gap) is connected between the low-tension terminal of the capacitor and earth, see figure A.2.

The calibration of the complete measuring system is made by injection of known charges between the calibration terminals. According to IEC 60270, a calibration generator consists of a step voltage pulse generator with short rise time and a small series capacitor of known capacitance C_0. The rise time should be not more than 0,1 µs and C_0 should be in the range of 50 pF to 100 pF. When this generator is connected between two calibration terminals presenting a capacitance much greater than C_0, the injected charge from the pulse generator will be:

$$q_0 = U_0 \times C_0$$

where U_0 is the voltage step (usually between 2 V and 50 V).

It is convenient if the calibration generator has a repetition frequency of the order of one impulse per half cycle of the power frequency used for the test on the transformer.

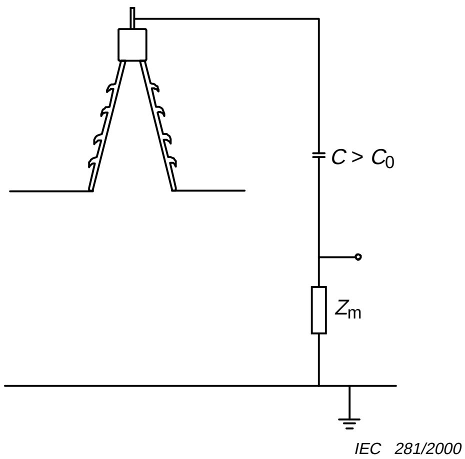


Figure A.2 – Circuit for partial discharge measurement using a high-voltage coupling capacitor

If the calibration terminals are spaced far apart, there is a risk that stray capacitances from the connecting leads may cause errors. One method which is applicable for calibration between earth and another terminal is shown in figure A.1.

Capacitor C_0 is then placed at the high-voltage terminal and a coaxial cable with a matching resistor is used from the step voltage generator.

If neither of the calibration terminals is earthed, the capacitance from the pulse generator itself will also be a source of error. The generator should preferably be battery-operated and have small physical dimensions.

A.3 Instruments, frequency range

The characteristics of the measuring instruments should be as specified in IEC 60270.

Oscillographic monitoring of the test is generally useful, particularly because it offers a possibility of discriminating between true partial discharge in the transformer and certain forms of external disturbances. This is based on rate of repetition, point on the wave, polarity differences, etc.

The indications should be observed continuously or at frequent intervals throughout the test period. Continuous recording by oscillograph or tape recorder is not obligatory.

Measuring systems for partial discharges are classified as narrow-band or wideband systems. A narrow-band system operates with a bandwidth of about 10 kHz or less at a certain tuning frequency (for example, radio noise meters). A wideband system utilizes a relatively large ratio between lower and upper limits of the frequency band, for example 50 kHz to 150 kHz, or even 50 kHz to 400 kHz.

By the use of a narrow-band system, interference from local broadcasting stations may be avoided by suitably adjusting the mid-band frequency, but a check has to be made to show that winding resonances near the measuring frequency do not greatly effect the measurement. The narrow-band instrument should be operated at a frequency no higher than 500 kHz, and preferably less than 300 kHz. There are two reasons for this. First, the transmission of the discharge pulse entails a high attenuation of the higher frequency components, and second, when applying a calibration pulse to the line terminal, the pulse is likely to excite local oscillations at and near the terminal, and this will complicate the calibration when mid-band frequencies greater than 500 kHz are used.

A wideband measuring system is less critical as to attenuation and response to different pulse shapes, but is more receptive to disturbances in test locations without electromagnetic shielding. Band-stop filters may be used against radio transmitters. Identification of partial discharge sources by comparison of shape and polarity of individual pulses may be possible.

NOTE Today's broad-band instruments differ largely in their evaluation modes and built-in filter characteristics. Together with the complicated pulse transfer mode from within the windings and the decaying frequency spectrum of the responses each instrument will yield a different apparent charge reading despite the well-established calibration procedures. The latest revision of IEC 60270 indicates this problem but fails to standardize broad-band measuring instruments. This problem does not exist for narrow-band meters with CISPR 16-1 pulse repetition evaluation.

A.4 Test criteria – Procedure after an unsuccessful test

At the end of 12.2, 12.3 and 12.4, acceptance criteria are given. The steady-state partial discharge level, expressed as an apparent charge measured between the prescribed measuring terminals, should not be above the specified limit, and there should not be a significant rising trend during the total test duration.

If there has been no voltage collapse, but the test has been unsuccessful because of too high but still moderate partial discharge reading (within a few thousand picocoulombs or less), the test is regarded as non-destructive. A further criterion of importance is that the partial discharges are not sustained into or below the operating voltage level, when triggered at the test level.

The test object should not be rejected immediately upon such a result, but further investigations should be undertaken.

The testing environment should first be investigated to find any obvious sign of irrelevant sources of partial discharges. This should be followed by consultations between the supplier and purchaser to agree on further supplementary tests or other action to show either the presence of serious partial discharge, or that the transformer is satisfactory for service operation.

Below are some suggestions which may be useful during the above courses of action.

Investigation as to whether the indications are truly correlated to the test sequence or just represent coincident, irrelevant sources. This is often facilitated by oscillographic monitoring of the test, disturbances may for example be identified by their being asynchronous with the test voltage.

Investigation as to whether the partial discharge may be transmitted from the supply source. Low-pass filters on the supply leads to the transformer under test can help in such cases.

Investigation to determine whether the partial discharge source is within the transformer or outside (spitting from objects at floating potential in the hall, from live parts in air, or from sharp edges on earthed parts of the transformer). As the test concerns the internal insulation, provisional electrostatic shielding on the outside is permitted and recommended.

Investigation of the probable location of the source(s) in terms of the electrical circuit diagram of the transformer. There are several known and published methods. One is based on correlation of readings and calibrations at different pairs of terminals (in addition to the obligatory readings between line terminals and earth). It is described in clause A.5. It is also possible to identify individual pulse shapes during the test with corresponding calibration waveforms, if records from wideband circuits are used. A particular case is the identification of partial discharge in the dielectric of the capacitance graded bushings, see end of clause A.5.

Investigation by acoustic or ultrasonic detection of the "geographical" location of the source(s) within the tank.

Determination of the probable physical nature of the source by conclusions drawn from variation with test voltage level, hysteresis effect, pulse pattern along the test voltage wave, etc.

Partial discharge in the insulation system may be caused by insufficient drying or insufficient oil impregnation. Re-processing of the transformer, or a period of rest, and subsequent repetition of the test may therefore be tried.

It is also well known that a limited exposure to a relatively high partial discharge may lead to local cracking of oil and temporarily reduced extinction and re-inception voltages, but that the original conditions may be self-restored in a matter of hours.

If the partial discharge indications are above the acceptance limit but are not considered as very important, it may be agreed to repeat the test, possibly with extended duration, and even with increased voltage level. Relatively limited variation of the partial discharge level with voltage increase, and absence of increase with time, may be accepted as evidence that the transformer is suitable for service.

Traces of partial discharges visible after untanking are usually not found unless the transformer has been exposed for a considerable duration of time to levels which are very high in comparison with the acceptance limit. Such a procedure may be the last resort if other means of improving the behaviour of the transformer or identifying the source have failed.

A.5 Electrical location of partial discharge sources by means of "multi-terminal measurement" and "profile comparison"

An arbitrary partial discharge source will deliver signals at all accessible *measuring terminal pairs* of the transformer, and the pattern of these signals is a unique "finger-print". If calibration pulses are fed in at alternative *calibration terminal pairs*, these pulses also deliver combinations of signals at the *measuring pairs*.

If there is an evident correlation between the profile of the test readings at different measuring terminal pairs and the profile obtained at the same measuring terminals for pulses fed in at a particular pair of calibration terminals, then it is assumed that the actual partial discharge source is closely associated with this calibration pair.

This means that it is possible to draw a conclusion as to the electrical location of the partial discharge source in terms of the electric circuit diagram of the transformer. The "physical location" is a different concept; a partial discharge source which is "electrically" located in the vicinity of a particular terminal may be physically located at any place along the terminal conductors associated with this terminal or at the corresponding end of the winding structure. The physical location of the p.d. source would usually be determined by acoustic localization techniques.

The procedure for obtaining the profile comparison is as follows.

While the calibration generator is connected to a specific pair of calibration terminals, the indications at all pairs of measuring terminals are observed. The procedure is then repeated for other pairs of calibration terminals. Calibrations are made between winding terminals and earth, but may also be applied between the live terminals of the high-voltage bushings and their capacitance taps (simulating partial discharge in the bushing dielectric), between high-voltage and neutral terminals, and between high-voltage and low-voltage winding terminals.

All combinations of calibration and measuring pairs form a "calibration matrix" which gives the interpretation reference for the readings in the actual test.

For example, figure A.3 shows an extra-high-voltage single-phase auto-connected transformer with a low-voltage tertiary winding. Calibrations and tests are made with reference to the terminals as indicated in the table. The line with results at 1,5 U_m is compared with the different calibrations, and it is easy to see, in this case, that it corresponds best to calibration "terminal 2.1 – earth". This suggests that there are partial discharges with apparent charge of the order of 1 500 pC associated with terminal 2.1, and probably from live parts to earth. The physical location may be at any place along the connecting leads between the series winding and common winding, or at the adjacent winding ends.

The method as described is successful mainly in those cases where one distinct source of partial discharge is dominant and the background noise is low. This is certainly not always the case.

A particular case of interest is to determine whether observed partial discharges may originate in the high-voltage bushing dielectric. This is investigated by a calibration between the bushing line terminal and the value of the capacitance graded bushing tap. This calibration gives the closest correlation to the profile of partial discharges in the bushing.

Channel	**1.1**	**2.1**	**2.2**	**3.1**
Calibration	**Arbitrary units**			
1.1 – earth 2 000 pC 2.1 – earth 2 000 pC 2.2 – earth 2 000 pC 3.1 – earth 2 000 pC	50 5 2 3	20 50 10 2	5 30 350 35	10 8 4 25
Test $U = 0$ $U = U_m$ $U = 1{,}5\ U_m$	 <0,5 <0,5 6	 <0,5 <0,5 40	 <0,5 0,5 25	 <0,5 0,5 8

NOTE For improving effectivity, also terminals 2.2 and 3.2 should be treated as measuring and calibration terminals, particularly when capacitance graded bushings are provided.

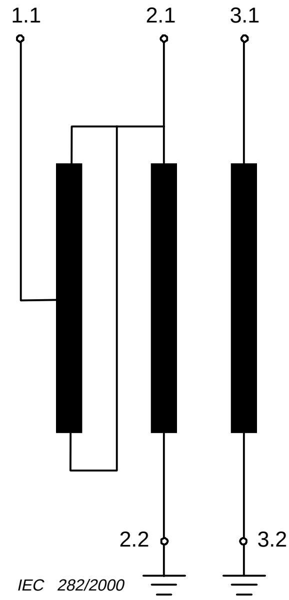


Figure A.3 – Location of partial discharge sources by means of "multi-terminal measurement" and "profile comparison"

Annex B
(informative)

Overvoltage transferred from the high-voltage winding to a low-voltage winding

B.1 General

The problem of transferred overvoltage is treated from a system viewpoint in annex A of IEC 60071-2. The information given below concerns only problems associated with the transformer itself under particular conditions of service. The transferred overvoltages to be considered are either transient surges or overvoltages.

NOTE It is the responsibility of the purchaser to define the loading of a low-voltage winding. If no information can be given, the supplier can provide information about the expected transferred voltages when the low-voltage terminals are open-circuited, and about the values of ohmic resistors or capacitors which are needed to keep the voltages within acceptable limits.

B.2 Transfer of surge voltage

B.2.1 General

A study of particular transformer installation with regard to transferred surge overvoltages is, in general, justified only for large generator transformers, which have a large voltage ratio, and for large high-voltage system transformers with a low-voltage tertiary winding.

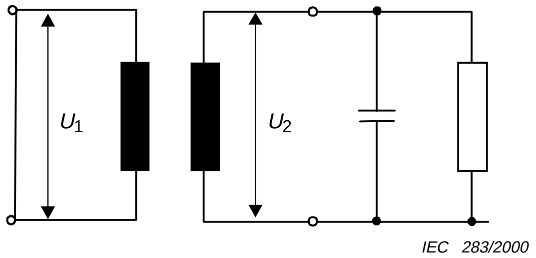
It is convenient to distinguish between two mechanisms of surge transfer, namely *capacitive transfer* and *inductive transfer*.

B.2.2 Capacitive transfer

The capacitive transfer of overvoltage to a low-voltage winding may in the first approximation be described as a capacitive voltage division. The simplest equivalent circuit as seen from the low-voltage winding consists of an electromotive force (e.m.f.) source in series with a transfer capacitance C_t, see figure B.1.

The equivalent e.m.f. is a fraction s of the incoming surge on the high-voltage side. C_t is of the order of 10^{-9} F; s and C_t are not well-defined quantities but dependent on the shape of the surge front. They can be determined together by oscillographic measurements. Pre-calculation is uncertain.

A loading of the secondary terminals with switchgear, short cables or added capacitors (a few nF), which act as lumped capacitance C_s directly on the terminals (even during the first microsecond), will reduce the transferred overvoltage peak. Longer cables or busbars are represented by their characteristic impedance. The resulting shape of secondary overvoltage will normally have the character of a short (microsecond) peak, corresponding to the front of the incoming surge.



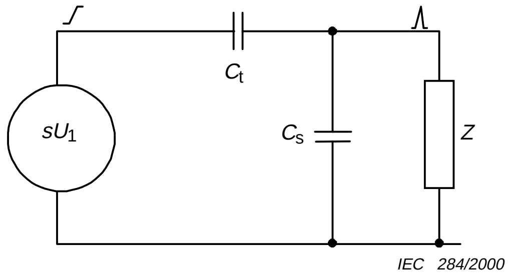


Figure B.1 – Equivalent circuit for capacitive transfer of overvoltage

B.2.3 Inductive transfer

The inductive transfer of surge voltage depends on the flow of surge current in the high-voltage winding.

If no external loading is applied to the secondary winding, the voltage transient usually has a superimposed damped oscillation with a frequency determined by leakage inductance and winding capacitances.

A reduction of the inductively transferred overvoltage component can be effected either by resistive damping through a surge diverter or by modification of the oscillation with capacitive loading. If capacitors are used, the capacitance value has usually to be of the order of tenths of microfarads. (They will therefore automatically eliminate the capacitively transferred component as long as the circuit inductance is low.)

The transformer parameters which are involved in inductive surge transfer are better defined and less dependent on rate of rise (or frequency) than those involved in capacitive transfer. For further information, see the literature on the subject.

B.3 Power-frequency transferred overvoltage

If a low-voltage winding which is physically adjacent to the high-voltage winding is left without connection to earth or with only a high-impedance connection to earth while the high-voltage winding is energized, there is a risk of power frequency overvoltage by capacitance division.

The risk is obvious for a single-phase winding, but it can also exist for a three-phase winding if the primary winding voltage becomes asymmetric, as occurs during earth faults. In particular circumstances, resonance conditions may arise.

Tertiary windings and stabilizing windings in large transformers are also subjected to the same risk. It is the responsibility of the purchaser to prevent a tertiary winding from being accidentally left with too high an impedance to earth. A stabilizing winding should normally be arranged for permanent connection to earth (tank) either externally or internally.

The overvoltage is determined by capacitances between windings and between windings and earth. These can be measured at low frequency from the terminal of the transformer in different combinations, and they can also be calculated with sufficient accuracy.

Annex C
(informative)

Information on transformer insulation and dielectric tests to be supplied with an enquiry and with an order

For all windings:

– Value of U_m for the line terminals and the assigned U_m for the neutral terminals.

– Connection of the windings (Y, D or zig-zag).

– Rated withstand voltages constituting the insulation level for line terminals, see table 1.

– Whether the winding is to have uniform or non-uniform insulation, and in the case of non-uniform insulation, the AC withstand voltages of the neutral.

– Whether a rated impulse withstand level is assigned to the neutral, and, in such a case, the appropriate withstand voltage.

– Whether the lightning impulse test on the line terminals is to include a chopped impulse test.

For transformers having a high-voltage winding with U_m = 245 kV:

– Whether the switching impulse test is to be omitted (only if the short-duration AC induced withstand test is specified, see table 1).

For transformers having a high-voltage winding with $U_m \geq 245$ kV:

– If the short-duration induced test is specified, the procedure for performing the test for uniform insulation according to 12.2 and for non-uniform insulation according to 12.3 should be specified.

It is further recommended that test connections and procedures should be discussed at the time of placing the order or at the design review stage, particularly with regard to the connection for induced withstand voltage tests on complicated transformers with non-uniformly insulated high-voltage windings (see 12.3, note) and the method to be used for impulse tests on high-power low-voltage windings and neutral terminals (see 13.3). The application of non-linear protection devices, built into the transformer is to be indicated by the supplier at the enquiry and at the order stage, and should be shown in the connection diagram at the rating plate.

Annex D
(normative)

ACSD

Table D.1 – Test voltages for short-duration withstand voltage test for uniformly insulated transformers with U_m > 72,5 kV according to tables 2 and 4 and subclause 12.2.2

Highest voltage for equipment U_m kV r.m.s.	**Rated short-duration induced or separate source a.c. withstand voltage according to tables 2, 3 or 4** kV r.m.s.	**Test voltage U_1 phase-to-phase** kV r.m.s.	**Partial discharge evaluation level phase-to-earth** $U_2 = 1,3 \frac{U_m}{\sqrt{3}}$ kV r.m.s.	**Partial discharge evaluation level phase-to-phase** $U_2 = 1,3\ U_m$ kV r.m.s.
100	150	150	75	130
100	185	185	75	130
123	185	185	92	160
123	230	230	92	160
145	185	185	110	185
145	230	230	110	185
145	275	275	110	185
170	230	230	130	225
170	275	275	130	225
170	325	325	130	225
245	325	325	185	320
245	360	360	185	320
245	395	395	185	320
245	460	460	185	320
300	395	395	225	390
300	460	460	225	390
362	460	460	270	470
362	510	510	270	470
420	460	460	290	505
420	510	510	290	505
420	570	570	315	545
420	630	630	315	545
550	510	510	380	660
550	570	570	380	660
550	630	630	380	660
550	680	680	380	660

NOTE 1 For U_m = 550 kV and part of U_m = 420 kV, the p.d. evaluation level should be reduced to 1,2 $U_m/\sqrt{3}$ and 1,2 U_m respectively.

NOTE 2 When the ACSD withstand voltage U_1 is smaller than the p.d. phase-to-phase evaluation level U_2, U_1 should be taken as equal to U_2. Internal and external clearances should be designed accordingly.

Table D.2. – Test voltages for short-duration withstand voltage test for non-uniformly insulated transformers with U_m > 72,5 kV according to tables 2 and 4 and subclause 12.3

Highest voltage for equipment U_m kV r.m.s.	**Rated short-duration induced or separate source a.c. withstand voltage according to tables 2, 3 or 4** kV r.m.s.	**Test voltage U_1 phase-to-earth equal to phase-to-phase** kV r.m.s.	**Partial discharge evaluation level phase-to-earth** $U_2 = 1,5 \frac{U_m}{\sqrt{3}}$ kV r.m.s.	**Partial discharge evaluation level phase-to-phase** $U_2 = 1,3\ U_m$ kV r.m.s.
100	150	150	87	130
100	185	185	87	130
123	185	185	107	160
123	230	230	107	160
145	185	185	125	185
145	230	230	125	185
145	275	275	125	185
170	230	230	145	225
170	275	275	145	225
170	325	325	145	225
245	325	325	215	320
245	360	360	215	320
245	395	395	215	320
245	460	460	215	320
300	395	395	260	390
300	460	460	260	390
362	460	460	315	460
362	510	510	315	460
420	460	460	365	504
420	510	510	365	504
420	570	570	365	545
420	630	630	365	545
550	510	510	475	660
550	570	570	475	660
550	630	630	475	660
550	680	680	475	660

NOTE 1 For U_m = 550 kV and part of U_m = 420 kV, the p.d. evaluation level should be reduced to 1,2 $U_m/\sqrt{3}$ and 1,2 U_m respectively.

NOTE 2 When the ACSD withstand voltage U_1 is smaller than the p.d. phase-to-phase evaluation level U_2, U_1 should be taken as equal to U_2. Internal and external clearances should be designed accordingly.

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